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Analyzing publicly available videos about recreational fishing reveals key ecological and social insights: a case study about groupers in the Mediterranean Sea

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ABSTRACT

iEcology and conservation culturomics are two emerging research approaches that rely on digital data for studying ecological patterns and human-nature interactions. We applied data mining of videos published on YouTube related to recreational fishing of four species of groupers (family: Epinephelidae) in Italy between 2011 and 2017 to learn whether digital user-supplied data help uncover key spatio-temporal ecological patterns characteristic of the studied species. Our results support an ontogenetic deepening of the dusky grouper (Epinephelus marginatus) as revealed by a positive relationship between body mass and depth of captures declared in spearfishing videos. In addition, the data support a northward expansion of the white grouper (Epinephelus aeneus) because the average latitude associated to the catch was found to be positively correlated with the years when the videos were uploaded on YouTube. Furthermore, the georeferenced data about the white grouper filled a knowledge gap in a well-established international occurrence records dataset. The approach presented here could help mitigating data deficiencies and inform about harvesting patterns shown by recreational anglers and spearfishers. Our work illustrates the value of digital data associated with recreational fishing for advancing fish and fisheries research. The approach can be broadened to larger spatial and temporal scales, and to different species, contributing to a better understanding of macroecological patterns, assessment and conservation of exploited species, and monitoring of recreational fisheries.

KEYWORDS: depth refuge hypothesis, ontogenetic deepening, meridionalization, northward expansion, angling, spearfishing

INTRODUCTION

Scientists increasingly recognize the value of data gathered from non-traditional user supplied sources, such as fishers' local ecological knowledge, as a complement to scientific data for advancing marine ecology, resource conservation and management (e.g., Azzurro et al., 2019; Sáenz–Arroyo et al., 2005). In recent decades, many aspects of human culture, knowledge, and social interactions are being regularly recorded online in digital format (Reed, 2018). This has fostered the emergence of new research areas: iEcology (Jaric et al., 2020) and conservation culturomics (Ladle et al., 2016). Although both research areas applied quantitative analysis of large bodies of digital data, iEcology aims to characterize ecological patterns and processes (e.g., species occurrences, distributional range shifts; Jaric et al., 2020) using data generated for other purposes, while conservation culturomics aims to characterize and understand contemporary problems in conservation by looking at them from the perspective of human-nature interactions (e.g., attitudes of stakeholders, human behavior in the context of resource exploitation; Ladle et al., 2016). The systematic analysis of digital data in both research areas constitutes a promising research approach, which can also contribute to fisheries science and may allow examining specific ecological hypotheses.

iEcology and conservation culturomics are particularly interesting in the context of recreational fisheries because of the many people that are involved in this activity, of which a sizable fraction uses digital platforms on the internet. New monitoring and assessment methods tailored towards recreational fishing have been developed to collect and analyze data from digital platforms (e.g., Carter et al., 2015; Martin et al., 2014; Monkman et al., 2018b; Sbragaglia et al., 2019a; Venturelli et al., 2017). For example, digital information of catches by recreational fishers constitutes a widespread

77 spatio-temporal network of samples that - if appropriately analyzed - can provide an
78 unprecedented body of information, especially for aquatic environments where
79 sampling is constrained across time and space. In this context, data mining on YouTube
80 is of particular interest because YouTube represents a worldwide dynamic cultural
81 system (Burgess and Green, 2018), which is embedded into the recreational fishers'
82 culture (Sbragaglia et al., 2019a). Recreational fishers often share videos of their catches
83 or memorable fishing trips together with other important information such as the mass
84 of the fish, the depth of capture, and the place of capture. Mining data about
85 recreational fishing from YouTube can foster new opportunities for comparative studies
86 among recreational fishing modalities, such as angling and spearfishing (Sbragaglia et
87 al., 2019a), which can support marine science, resource conservation and management.
88 Groupers (family: Epinephelidae) are iconic and emblematic top predators of
89 coral and rocky reefs around the world (Hackradt et al., 2014; Heemstra, 1993; Sadovy
90 de Mitcheson et al., 2013). Groupers can have a keystone role from an ecological
91 (Libralato et al., 2006; Valls et al., 2015) and cultural (Garibaldi and Turner, 2004)
92 perspective. Several species of groupers are exploited in commercial (Sadovy de
93 Mitcheson et al., 2013) and recreational (Giglio et al., 2017) fisheries. Simultaneously,
94 groupers are also charismatic and important species for recreational divers (Giglio et al.,
95 2015; Gill et al., 2015). Since 1998, the International Union for Conservation of Nature
96 (IUCN) established the grouper and wrasse specialist group due to growing concern for
97 these species' conservation status. The global results of the IUCN Red List assessment
98 indicated that among 163 grouper species evaluated, 42 species show a risk of extinction
99 in the wild or were Near Threatened (NT), and 50 species lacked sufficient data to
100 perform an accurate assessment (i.e., they were Data Deficient, DD; Luiz et al., 2016;

101 Sadovy de Mitcheson et al., 2013). Poor management of grouper fisheries can have
102 substantial ecological, social and economic implications for coastal communities
103 worldwide (Luiz et al., 2016). While previous studies have indicated that fisher's
104 knowledge can contribute to assessment of species at risk, such as groupers (e.g., Sáenz–
105 Arroyo et al., 2005), the use of digital data for similar purposes remains underexplored.
106 Here, we focus on the analysis of YouTube videos featuring recreational fishing
107 of four target species of groupers in Italy as a case study for the Mediterranean Sea,
108 which is one of the areas of the world where several Data Deficient grouper species are
109 predicted to be threatened (Luiz et al., 2016). We explore the potential application of an
110 iEcology approach to characterize spatio-temporal ecological patters, mitigate data
111 deficiencies, and inform about recreational harvest patterns. The first target species is
112 the dusky grouper (Epinephelus marginatus; see also Table 1), an emblematic species
113 for conservation in the Mediterranean Sea and a common target by many recreational
114 fishing modalities, especially spearfishing (e.g., Dedeu et al., 2019). It has been widely
115 accepted that selective spearfishing pressure on large individuals in shallow waters is
116 the major driver of the ontogenetic deepening (i.e., the pattern that older and larger
117 fish are found in deeper waters compared with smaller and younger individuals that
118 remain shallower) of the dusky grouper (García-Rubies et al., 2013; Harmelin and
119 Harmelin-Vivien, 1999; Reñones et al., 1999). Ontogenetic deepening can occur for
120 natural reasons of habitat preferences or may also be triggered by size-selective fishing
121 (Audzijonyte and Pecl, 2018; Frank et al., 2018). Specifically, the "depth refuge"
122 hypothesis predicts that larger individuals - the main target of spearfishers - will search
123 for protection in deeper water where spearfishers cannot operate (Lindfield et al.,
124 2014). However, the role of harvesting in driving ontogenetic deepening in exploited

stocks is still controversially debated (Audzijonyte and Pecl, 2018). This macroecological pattern – also known as Heincke's law (Cushing, 1975; Heincke, 1913) - has been widely described, but whether it is entirely caused by fishing exploitation, climate change, life-history adaptations, habitat preferences or a combination of all these factors is still largely unknown (Audzijonyte and Pecl, 2018; Baudron et al., 2019; Frank et al., 2018; Frank et al., 2019). If spearfishing harvesting is the most important driver of the ontogenetic deepening of the dusky grouper, videos posted on YouTube should document a positive relationship between depth and body mass of the catch associated with an increasing depth of catch across years. Such time-dependent relationships would strongly suggest an arms race between recreational spearfishers and groupers characterized by larger individuals seeking refuge from spearfishers in deeper water, and spearfishers systematically increasing their operating depth for chasing them.

The second target species of relevance in the Mediterranean is the white grouper (Epinephelus aeneus; see also Table 1), which is mainly targeted by recreational angling, especially trolling (Giovos et al., 2018), rather than spearfishing. The white grouper was considered to be absent in central Italy, but a specimen has been captured in January 2014 off Monaco (Pollard et al., 2018), and two other specimens have been recently caught off Corsica, France (Ruitort, 2012). Moreover, the species is also expanding northward in the Atlantic Ocean (Bañón et al., 2020). These records, together with other fishery-dependent data and anectodals reports from recreational fishers, suggest that the species may be extending its spatial distribution to the northern parts of the Mediterranean Sea (ĐoĐo et al., 2016; Dulčić et al., 2006; Glamuzina et al., 2000). If that is the case, records posted on YouTube by recreational fishers should document this pattern.

The last two target species studied here are the goldblotch grouper (Epinephelus costae) and the dogtooth grouper (Epinephelus caninus). The goldblotch grouper is mainly targeted by recreational trolling and spearfishing (Giovos et al., 2018), while the dogtooth grouper, which lives in deeper water than the other species studied here (Table 1), is mainly targeted by anglers due to the depth limitation of spearfishing. Both species were declared "Data Deficient" in the last Mediterranean IUCN report (Francour and Pollard, 2018a; Francour and Pollard, 2018b; Table 1), therefore we lack knowledge on their population trend data and, furthermore, their importance for recreational fishing in the region remain uncertain.

We first characterized the annual rhythms in the upload patterns of videos by recreational anglers and spearfishers, which could indicate differences in catchability of groupers throughout the year as previously suggested for recreational fishing of the common dentex, Dentex dentex (Sbragaglia et al., 2019a). Moreover, we documented the declared mass and depth of the groupers showed in the videos to reveal possible differences in the harvesting patterns between recreational anglers and recreational spearfishers (Sbragaglia et al., 2019a). Next, we tackled the following ecological questions:

(i) Does the declared mass of the dusky grouper increase with the depth in the spearfishing videos supporting an ontogenetic deepening?

(ii) Does the declared depth of the dusky grouper increase across years in the spearfishing videos supporting an arms race between groupers and spearfishers?

(iii) Does the geographical pattern of the location declared in the videos support a northward expansion of the white grouper?

MATERIALS AND METHODS

Ethical aspects

The data we mined from YouTube are publicly available. However, we followed the framework presented by Monkman et al. (2018a) on the ethics of using social media in fisheries research and the recent guidelines presented by Di Minin E. et al. (in press) for ensuring data privacy concerns are fully considered and the European Union's (EU) General Data Protection Regulation (GDPR) is complied with when using social media data. Specifically, we minimized the data by discarding all but required information and pseudonymisated them by replacing IDs (e.g., channel title, channel ID). Finally, we kept all data related to personal information in one dataset, while the rest of data presented in the paper were stored in another dataset.

Study system and fishing forms examined

We explored recreational fishing of groupers in Italy. We mined data from 2011 to 2017 by using a systematic analysis to collect quantitative and semi-quantitative data on harvesting patterns from YouTube videos (Correia et al., in press). We automatically retrieved the metadata of videos published concerning the species of interest and sorted them into two groups: one related to captures by recreational angling and the other one related to captures by recreational spearfishing. Spearfishing was defined as underwater fishing practiced by the exclusive use of free-diving techniques and a speargun (e.g., Sbragaglia et al., 2018); angling was defined as hook-and-line fishing from either the coastline or from a boat with natural baits or artificial lures.

Data mining and cross check of automatic identification

We collected the data using the YouTube Data API (v3), following the steps reported in a previous study (Sbragaglia et al., 2019a). First, we extracted the data from YouTube's API in October 2018 using one single keyword represented by the common name of groupers in Italian ("cernia"). Although the use of both vernacular and scientific names is suggested (Correia et al., 2018), the use of the common name "cernia" allows identifying videos related to the target species of our study: dusky, white, goldblotch, and dogtooth groupers. We compiled a raw dataset with the title and descriptions of videos.

In a second step, we automatically searched the title and description of each video for specific keywords that were already used in a previous study (Sbragaglia et al., 2019a). The keywords were subdivided into two groups with the aim to sort the videos regarding recreational angling and recreational spearfishing. Finally, we stored the results in a dataset that was subsequently manually cross checked.

We excluded the videos that were: (i) not related to the target species; (ii) not showing the catch of the target species (i.e., catch and release or not shooting while spearfishing); (iii) not related to the target country; and (iv) duplicates of previously published videos. Then, we applied a manual cross check of the automatic classification to identify the occurrence of false negatives (i.e., target videos previously not recognized following the keywords), false positives (i.e., videos erroneously attributed to one of the two groups) and mismatched categorizations (i.e., videos erroneously attributed to one fisher group instead of the other). Finally, during the manual cross check, we explored the content of videos and annotated the species, the mass of the fish, and the depth at which the fish was captured by screening the title or description of the videos as well as the video footage itself. We also annotated the location of the videos related to the

white grouper. We run all the analyses related to data mining in R (https://www.r-project.org/; version 3.5.0) with the additional package "jsonlite" (Ooms, 2014), "lubridate" (Grolemund and Wickham, 2011), and "curl" (https://cran.r-project.org/web/packages/curl/index.html).

Data analysis

We estimated annual periodicity of the upload patterns of videos for each of the four target species and each group (angling and spearfishing) by using RAIN (rhythmicity analysis incorporating nonparametric methods). This method is a robust non-parametric method for the detection of rhythms in data that can detect arbitrary oscillations (Thaben and Westermark, 2014). We estimated differences in declared mass and depth between angling and spearfishing using: (i) a two-sample unpaired Welch's t-test (a parametric test that better controls Type 1 error when the assumption of homogeneity of variance is not met; Delacre et al., 2017), followed by the estimation of Cohen's d effect sizes (Cohen, 1988); or (ii) the non-parametric Mann–Whitney U test followed by the estimation of Vargha and Delaney's A effect sizes (Vargha and Delaney, 2000), which accounted for cases where the distribution of response variable did not allow the use of a parametric statistical test. Next, the relationship between declared depth and body mass for spearfishing videos related to the dusky grouper (question i) was estimated using a linear regression model; while the correlation between the declared depth and years for the spearfishing videos related to the dusky grouper (question ii) as well as the correlation between latitude and years for the white grouper (question iii) were estimated using the Kendall's rank correlation coefficient (r_τ) because data did not meet the assumptions to use parametric statistical tests. In the cases in which we used

parametric tests, response variables were transformed by finding the exponent (lambda), as a power transformation producing a normally distributed response variable. We assessed model fits by checking the plot of the residuals vs. the fitted values. In all cases we used a 95% confidence interval. We run all the analyses related to data mining in R (https://www.r-project.org/; version 3.5.0) with the additional package "rain" (Thaben and Westermark, 2014); "rcompanion" (https://CRAN.R-project.org/package=rcompanion); "lsr" (https://cran.r-project.org/web/packages/lsr); "effsize" (https://cran.r-project.org/web/packages/effsize).

RESULTS

We identified a total of 2097 videos published between 2011 and 2017: 1714 (82%) videos were related to spearfishing and 383 (18%) related to angling. We sorted the videos identified among the four target species: 1670 related to the dusky grouper (80%); 262 related to the white grouper (12%); 100 related to goldblotch grouper (6%); and 32 related to dogtooth grouper (1%). We were not able to assign a species to the groupers fished in 33 videos (1%; Table 2).

Dusky grouper

Among the 1670 videos identified for the dusky grouper (Fig. 1), 171 were related to angling (10%), while 1499 were related to spearfishing (90%). The upload of spearfishing videos indicated a significant ($p < 0.001$) annual periodicity with a peak in August (Fig. 2A), while angling videos did not show significant annual periodicity ($p = 0.976$). We retrieved the body mass declared in a total of 460 videos (34 for angling and 426 for spearfishing). The declared body mass was significantly ($t_{41.97} = 6.46$; $p < 0.001$; $d = 0.94$)

higher in angling videos (mean = 13.6 kg; SD = 6.1 kg) than in spearfishing ones (mean = 8.4 kg; SD = 5.3 kg; Fig. 2B). We retrieved the declared depth of dusky grouper capture in a total of 155 videos (6 for angling and 149 for spearfishing). The declared depth showed that values for angling videos were significantly ($U = 891$; $p < 0.001$; $A = 0.99$) higher (median = 67 m) than those for spearfishing videos (median = 24 m; Fig. 2C). Finally, we retrieved a total of 75 videos of spearfishing related to the dusky grouper where we were able to assess both depth and body mass of the specimen shown in the video. We found a significant positive correlation between declared depth and body mass ($R = 0.17$; $F_{1,73} = 15.3$; $p < 0.001$), indicating that larger dusky grouper captures tended to occur in deeper sites (Fig. 2D). The declared depth for the spearfishing videos was not significantly correlated with years ($r_\tau = -0.08$; $p = 0.146$; $N = 149$; Fig. 2E), and thus we did not find evidence of a deepening of spearfishing efforts in recent years.

White grouper

Among the 262 videos identified for the white grouper, 136 were related to angling (52%), while 126 were related to spearfishing (48%). The upload patterns of both groups did not indicate significant annual periodicity (angling: $p = 0.988$; spearfishing: $p = 0.999$; Fig. 3A). We retrieved the declared body mass of the white grouper in a total of 67 videos (42 for angling and 25 for spearfishing). The declared body mass was significantly ($t_{42.69} = 4.66$; $p < 0.001$; $d = 1.24$) higher in angling videos (mean = 11.3 kg; SD = 5.5 kg) than in spearfishing ones (mean = 6.6 kg; SD = 4.2 kg; Fig. 3B). We retrieved the declared depth of capture for white groupers in a total of 21 videos (6 for angling and 15 for spearfishing). The declared depths in angling videos were significantly ($U = 80$; $p < 0.01$; $A = 0.89$) higher (median = 44 m) than those for spearfishing videos (median = 29 m; Fig.

293 3C). Finally, we retrieved the location of fishing effort in a total of 64 videos (44 for
294 angling and 20 for spearfishing) and found a significant positive correlation between
295 latitude and years (r_τ = 0.25; $p < 0.01$), which suggests a northward shift in fishing
296 locations from 2011 to 2017 (Fig. 3D). The location of the videos was mostly from the
297 South of Italy (Fig. 3E).
298
299 Goldblotch grouper
300 Among the 100 videos identified for the goldblotch grouper, 25 were related to angling
301 (25%), while 75 to spearfishing (75%). The upload patterns of both groups did not
302 indicate significant annual periodicity (angling: p = 1; spearfishing: p = 0.999; Fig. 4A).
303 We retrieved the body mass declared for the goldblotch grouper in a total of 15 videos
304 (1 for angling and 14 for spearfishing). Only one angling video declared the body mass
305 for this species – 11 kg – but this mass is larger than any among those retrieved for
306 spearfishing videos (mean = 4.6 kg; SD = 1.7 kg; Fig. 4B). Finally, we retrieved the depth
307 declared for the capture of the goldblotch grouper in a total of 12 videos (2 for angling
308 and 10 for spearfishing). The depth declared in the two videos retrieved for angling was
309 32 and 49 m, which is within the range of depth declared for spearfishing videos (mean
310 = 35 m; SD = 11 m; Fig. 4C).
311
312 Dogtooth grouper
313 Among the 32 videos identified for the dogtooth grouper, 31 related to angling (97%)
314 and only 1 to spearfishing (3%). The upload pattern across years did not show significant
315 annual periodicity (angling: p = 1; Fig. 5A). We retrieved the body mass declared of the
316 dogtooth grouper in a total of 12 videos (all of them for angling). The declared mass

317 ranged from 15 to 60 kg (mean = 36 kg; SD = 14 kg; Fig. 5B). Finally, we retrieved the
318 depth declared for the capture of the dogtooth grouper in a total of 5 videos (all of them
319 for angling). The depth ranged from 61 to 443 m (Fig. 5C).
320
321 DISCUSSION
322 We show how data mining of recreational fishing on YouTube can provide large volumes
323 of data that are useful to characterize spatio-temporal ecological patterns, mitigate data
324 deficiencies, and inform about recreational harvesting patterns. Our results support two
325 ecological hypotheses possibly related to human disturbance and climate change effects
326 on groupers in the Mediterranean Sea. First, our results showed that the declared body
327 mass of the dusky grouper was positively correlated to the declared depth in
328 recreational spearfishing videos; this may support the depth refuge hypothesis (Lindfield
329 et al., 2014), but could also be explained by a natural ontogenetic deepening of the
330 species where larger fish use deeper habitats (Audzijonyte and Pecl, 2018). Second, our
331 work contributes to a large body of studies documenting a poleward expansion of fish
332 species in response to climate change (Burrows et al., 2011; Cheung et al., 2013) by
333 showing a positive correlation between latitude and the years in those videos in which
334 the capture of white groupers have been documented. Our results also confirm the
335 results of a previous study on recreational fishing of the common dentex on YouTube
336 (Sbragaglia et al., 2019a), by highlighting different harvesting patterns of groupers
337 between recreational anglers and recreational spearfishers.
338
339 The depth refuge hypothesis in the dusky grouper

We found support for an ontogenetic deepening of the dusky grouper by showing that the depth and the mass of the captured dusky grouper were positively related in spearfishing videos. Such pattern can be interpreted according to the depth refuge hypothesis, which was supported using fishery-independent data (i.e., baited remote underwater stereo-video systems) for SCUBA spearfishing on coral reef fish populations in the southern Mariana Islands (Lindfield et al., 2014). In particular, the authors found greater lengths of scarines and acanthurids in deeper waters (Lindfield et al., 2014). However, the declared depth in spearfishing videos of the dusky grouper did not increase over years, which suggests that spearfishers are not increasing their operating depth over the time period studied here (2011-2017). If fishing pressure for larger fish would be the most important driving force of the observed pattern, we might expect that the information associated to the videos would indicate a deeper fishing effort in response to ontogenetic deepening. However, this was not the case, and thus we have no support that the ontogenetic deepening is caused by size-selective harvesting over the time frame analyzed here.

There are three additional mechanisms that could explain the ontogenetic deepening of the dusky grouper that are not directly related to spearfishing harvesting: (i) small- and medium-sized individuals could have more pronounced preference for shallow waters than large individuals (e.g., Harmelin and Harmelin-Vivien, 1999); (ii) small- and medium-sized individuals could have a higher mortality rate in deeper water (Audzijonyte and Pecl, 2018), which in part can be caused by cannibalism (Condini et al., 2015), and (iii) larger individuals could move to deeper and cooler waters due to a growth/metabolism trade-off, which predicts that larger individuals allocate more energy to reproduction than smaller ones and therefore might move to cooler waters to

364 decrease their metabolic costs and thereby increase their fitness (Audzijonyte and Pecl,
365 2018; Frank et al., 2018; Macpherson and Duarte, 1991). Considering that the surface
366 water temperature of the north-western Mediterranean Sea is increasing (Bianchi et al.,
367 2018; Lejeusne et al., 2010), the growth/metabolism trade-off could indeed be one of
368 the drivers of the ontogenetic deepening of the dusky grouper.

369 In this context, selective harvesting of larger individuals - a common scenario in
370 many fisheries worldwide - could act at different levels on the ontogenetic deepening.
371 First, as highlighted by (Frank et al., 2018), intensive and selective harvesting of larger
372 individuals may reduce the number of older and larger individuals from highly-exploited
373 shallow water compared to less-exploited deeper waters. Second, the evolutionary
374 effects associated to selective harvesting of larger individuals could confound life-
375 history effects (Frank et al., 2018). For example, fisheries-induced evolution of life
376 history could affect the growth/metabolism trade-off by attenuating the ontogenetic
377 deepening in response to climate change. Indeed, fisheries-induced evolution may
378 foster the evolution of a fast life history that is characterized by elevated reproductive
379 investment, reduced age and size at maturation and reduced post maturation growth
380 and longevity (Heino et al., 2015). Therefore, individuals could move to deeper and
381 cooler waters at a smaller size and age because of anticipated maturation and increase
382 reproductive investment, attenuating the ontogenetic deepening. A further mechanism
383 associated to intense and selective-harvesting of larger individuals is related to behavior,
384 but escaped the attention of the recent discussion on this topic (Audzijonyte and Pecl,
385 2018; Frank et al., 2018). Experimental selective harvesting of larger individuals has
386 suggested that an evolutionary decrease of risk-taking behavior could happen
387 (Sbragaglia et al., 2019b), which in turn could increase the prevalence of shy fish (i.e.,

388 those less prone to take risks) in deep waters where there is less anthropogenic
389 disturbance compared to shallow waters (deep reef refugia concept; Bongaerts et al.,
390 2010). Such prediction is not only expected for spearfishing harvesting, which has been
391 shown to increase fish wariness (Januchowski-Hartley et al., 2011; Samia et al., 2019;
392 Sbragaglia et al., 2018), but also in other recreational and commercial fisheries triggering
393 a "timidity syndrome" in response to intensive harvesting (Arlinghaus et al., 2017 and
394 references therein). Moreover, it must be considered that the average depth of
395 spearfishing in free diving is reported to be around 18-25 m (FIPSAS, 2002). Although in
396 recent decades deep spearfishing at depth of 40-45 m has become more common, only
397 a minority of spearfishers can operate at such extreme depth, for example only 10% of
398 spearfishers operate at more than 25 m in the canary islands (Martín-Sosa, 2019). In
399 summary, our results suggest that the ontogenetic deepening of the dusky grouper
400 could not solely determine by spearfishing harvesting and the mechanisms explained
401 above could contribute in driving it. The relative contribution of the different
402 mechanisms is still unknown and represents an intriguing question for future research
403 in many fisheries worldwide (Audzijonyte and Pecl, 2018).
404
405 Northward expansion in the white grouper
406 Our results support a northward expansion of the white grouper during the time period
407 that we studied (2011-2017). We found a positive relationship between latitude at
408 which the white grouper catches were declared in the videos and the years of study. Our
409 results agreed with previous published records using different data sources that
410 documented an ongoing northward expansion of the white grouper. For example, two
411 specimens of white grouper were captured in the northern Adriatic Sea, which

represented the northernmost occurrence of the white grouper in the Mediterranean Sea (ĐoĐo et al., 2016; Dulčić et al., 2006). Our study shows a retrospective quantitative increase of the latitude across years related to the south Thyrrenian and Ionian Sea. Although our study is representative of only those recreational fishers sharing their catches on YouTube (possible associated biases are discussed below), it demonstrates that recreational fishers represent a widespread network of observers of ongoing changes of marine biota that can be quantitatively measured using data mining on social media. Indeed, the georeferenced records reported here about the white grouper filled a geographical gap in the occurrence records dataset of the Global Biodiversity Information Facility (GBIF; Fig. S1), which is an international network and research infrastructure funded by the world's governments and aimed at providing open access biodiversity data. As such, we argue that recreational fishers could represent an important monitoring tool for climate change effects on marine biota as recently demonstrated by using their local ecological knowledge in the context of meridionalization of the Mediterranean Sea (Sbragaglia et al., 2020).

Mitigation of data deficiency in goldblotch and dogtooth groupers

The IUCN status of Data Deficiency refers to lack of knowledge on distribution or population trend and implies that more information is required for the assessment of extinction risk (IUCN, 2012). Our study showed that publicly available videos about recreational fishing can provide additional and retrospective information and therefore can be a valuable additional tool for future assessment of species that are Data Deficient. Moreover, our results showed that the goldblotch grouper seems to be targeted preferentially by spearfishers compared to anglers. Information on

Mediterranean recreational fishing of goldblotch grouper could be scattered especially because it can be confounded with juveniles of the dogtooth grouper or the mottled grouper, Mycteroperca rubra (Coll et al., 2004). A systematic analysis of publicly available videos could overcome this limitation. As regarding the dogtooth grouper, it is preferentially targeted by recreational anglers because of clear depth-limitation of spearfishing. We documented a maximum declared mass that is close to the published records (Francour and Pollard, 2018a; Morales-Nin et al., 2005). Although recreational anglers may probably inflate the mass of the fish declared in the videos for increasing social engagement on YouTube, as previously suggested for recreational spearfishers (Sbragaglia et al., 2019a), our study suggests that large-sized species can be vulnerable to deep-sea angling. In this context, harvesting of dogtooth grouper is of special interest for Mediterranean deep-sea ecosystems because it is the grouper species with the deepest depth range and the maximum size and age (up to 60 kg and age of more than 50 years; Morales-Nin et al., 2005). The dogtooth grouper could be considered a keystone species (sensu Valls et al., 2015), and harvesting of large-sized individuals from the deep sea could have strong cascading effects on vulnerable ecosystems inhabited by this species such as deep coral reefs and seamounts (Canese and Bava, 2015; Francour and Pollard, 2018a). In general, harvesting of keystone predators may remove top-down control on ecosystems triggering trophic cascades (Frank et al., 2005) and alternative stable states (Palkovacs et al., 2018). This could be particularly important in the assessment of IUCN status of the dogtooth grouper because habitat alteration can be used to indirectly assign a specific threat category (IUCN, 2012).

Annual rhythms of capture

460 We only detected annual rhythms in the upload pattern of the spearfishing videos
461 related to the dusky grouper but not to the other three species. These results may
462 indicate – assuming that the videos are uploaded within few days after the fishing trip –
463 a seasonal change in the catchability of the dusky grouper species with peaks in August.
464 This may be related to a seasonal depth migration of the species that becomes more
465 accessible to spearfishers in shallow waters during the summer as suggested in a similar
466 study with the common dentex, Dentex dentex (Sbragaglia et al., 2019a). Indeed, in the
467 Western Mediterranean Sea the dusky grouper performs seasonal spawning migration
468 moving to shallow water during the summer as documented by direct observations
469 (Zabala et al., 1997) and telemetry data (Koeck et al., 2014). Such seasonal migrations
470 seem to usually occur in August (Zabala et al., 1997), which is also the month in which
471 we detected the peak of videos upload, supporting our interpretation. Additionally,
472 spearfishers may show seasonal patterns of fishing effort (e.g., peaks in August could be
473 associated to vacation times and more free time to go fishing) or annual periodicity in
474 the operating depth. In the latter case, Northern Mediterranean spearfishers wear a
475 thinner wetsuit in the summer than in winter to cope with changes of water
476 temperature, which implies the use of less weight during the summer that subsequently
477 increase the diving performance and hence the operating depth. Our results are in
478 contrast to what was shown in a recent study using local ecological knowledge of eastern
479 Mediterranean recreational fishers, where the fishing pressure on groupers was greater
480 in spring and autumn compared to the other seasons (Mavruk et al., 2018). Such
481 discrepancies could be related to the small sample size used in that study (N = 10), to
482 real differences between the two areas or to complementary data provided by the two

483 methods (local ecological knowledge and data mining on YouTube; see below for further
484 discussion).
485
486 Declared body mass and depth
487 We document that the declared body mass and depth in angling videos is greater than
488 in spearfishing videos for both the dusky and white groupers. These results are in
489 accordance to what was previously shown by mining data on recreational fishing of
490 common dentex (Sbragaglia et al., 2019a). In particular, catching a grouper (or a
491 common dentex) with spearfishing techniques requires more skills and usually long free
492 diving at considerable depths and elevated personal investment of energy relative to
493 angling (Sbragaglia et al., 2019a). Therefore, spearfishers are probably more stimulated
494 to post videos than anglers, including those showing the catch of relatively small
495 specimens. This could explain the differences in number of videos uploaded and the
496 differences in declared mass we observed in our study.
497 Our results partially disagree with local ecological knowledge of fishers in eastern
498 Mediterranean Sea, which indicated that the maximum size of the dusky grouper was
499 smaller for anglers compared to other fishing modalities including spearfishing (Mavruk
500 et al., 2018), while the maximum declared body mass we recorded was slightly larger
501 for anglers (30 kg) than spearfishers (27.5 kg). The same study reported the opposite for
502 the white grouper (i.e., smaller maximum size for spearfishing than other fishing
503 techniques, including angling; Mavruk et al., 2018), which agreed with our results
504 (angling max declared mass = 28 kg; spearfishers maximum declared body mass = 17 kg).
505 Finally, Mavruk et al. (2018) also reported that the average size of the white grouper
506 was smaller for angling compared to other fishing techniques, including spearfishing,

507 which disagreed with our results where we recorded a greater average body mass for
508 angling (11.3 kg) with respect to spearfishing (6.6 kg). As discussed above in the context
509 of annual rhythmicity, the observed discrepancies with the study by Mavruk et al. (2018)
510 could be related to several factors including complementary data provided by the two
511 methods. For example, Mavruk et al. (2018) reported that recreational anglers and
512 recreational spearfishers usually fish in shallow waters. Although this is true for
513 spearfishing for obvious depth-related operating constrains, our data show that
514 recreational anglers can operate at greater depth.
515
516 Challenges and limitations
517 Our results provide novel insights into ecological aspects and monitoring of groupers
518 targeted by recreational fishing in the Mediterranean Sea, but limitations must be
519 considered. First of all, the availability and representativeness of YouTube digital data
520 depends on accessibility to the internet and video recording technology, which are
521 strongly influenced by demography, socio-cultural and economic aspects (Correia et al.,
522 in press). Moreover, YouTube is a dynamic cultural system where algorithms for data
523 management often change and users can modify or delete information. Importantly,
524 mining data from YouTube is unlikely to be representative of the whole population of
525 recreational fishers and those fishers posting videos on YouTube probably represent the
526 most avid individuals (i.e., those recreational fishers that spend much of their time
527 fishing; Griffiths et al., 2013; Rocklin et al., 2014) as more specialized anglers usually
528 have larger degree of media interactions (Ditton et al., 1992). Therefore, it is very likely
529 that our data represent catches of the most efficient and skilled recreational fishers.

Furthermore, we extracted data from YouTube's API using one single keyword represented by the common name of groupers in Italian ("cernia"). This could have limited the amount of videos that are showing recreational catches of groupers without explicitly using the name in the title, description and tags of the videos. For example, several recreational fishers post compilations of catches that are difficult to identify with the methodology applied here, but could contain valuable data regarding groupers. This could have contributed to the overrepresentation of data related to the dusky grouper. In summary, the results presented here are not an absolute representation of recreational fisheries of groupers, but they represent a complementary contribution to existing knowledge (see also Fig. S1). Future challenges are represented by making data mining on social media more robust with the use of machine learning approaches (Roll et al., 2018; Toivonen et al., 2019) and by disentangling the proportion of recreational fishers posting their catches on social media and how much they differ from a representative population of recreational fishers.

Implications

Despite the limitations highlighted above, the approach we presented in our study is expected to strongly contribute to conservation and management of aquatic ecosystems in the coming years (Jaric et al., 2020; Ladle et al., 2016). One of the main reasons is that recreational fishers are more than 5 times the number of commercial capture fishers (Arlinghaus et al., 2019; FAO, 2018); for example, it has been estimated that Mediterranean marine recreational fishers are at about 8.7 million (Hyder et al., 2018). Therefore, recreational fishers can provide a unique network of detailed spatial and temporal representation of macroecological patterns. In particular the use of

554 YouTube as data source will certainly support these developments; in fact YouTube is
555 the second most visited website in the world (2 billion users) with 1 billion hours of
556 videos played every day in 80 different languages (YouTube, 2020).
557
558 Credit author statement
559 Valerio Sbragaglia: Conceptualization; Formal analysis; Funding acquisition;
560 Investigation; Visualization; Writing - original draft. Salvatore Coco: Data curation;
561 Validation; Writing - review & editing. Ricardo A. Correia: Methodology; Writing - review
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789

Table 1 – Summary of information related to the four target species of groupers. Depth range and conservation statuses are those reported by the IUCN red list Mediterranean assessment (https://www.iucnredlist.org). The intrinsic vulnerability index is extracted by FishBase (http://www.fishbase.org). Such index is calculated using a fuzzy logic expert system according to species life history and ecological characteristics associated to fishing vulnerability (the index values ranging from 1 to 100, with 100 being the most vulnerable; Cheung et al., 2005).

Species	Depth range (m)	Intrinsic vulnerability index	IUCN status (Mediterranean)
Dusky grouper (E. marginatus)	8-300	72/100	Endangered (EN)
White grouper (E. aeneus)	0-200	52/100	Near Threatened (NT)
Goldblotch grouper (E. costae)	20-80	66/100	Data Deficient (DD)
Dogtooth grouper (E. caninus)	30-400	87/100	Data Deficient (DD)

Table 2 – Number of videos related to recreational fishing of groupers mined on YouTube between 2011 and 2017. The different species with their common and scientific name are reported together with the number of videos mined for each recreational fishing modality.

Species	Modalities		Total
	Angling	Spearfishing	
Dusky grouper (E. marginatus)	171	1499	1670
White grouper (E. aeneus)	136	126	262
Goldblotch grouper (E. costae)	25	75	100
Dogtooth grouper (E. caninus)	31	1	32
Not identified	20	13	33

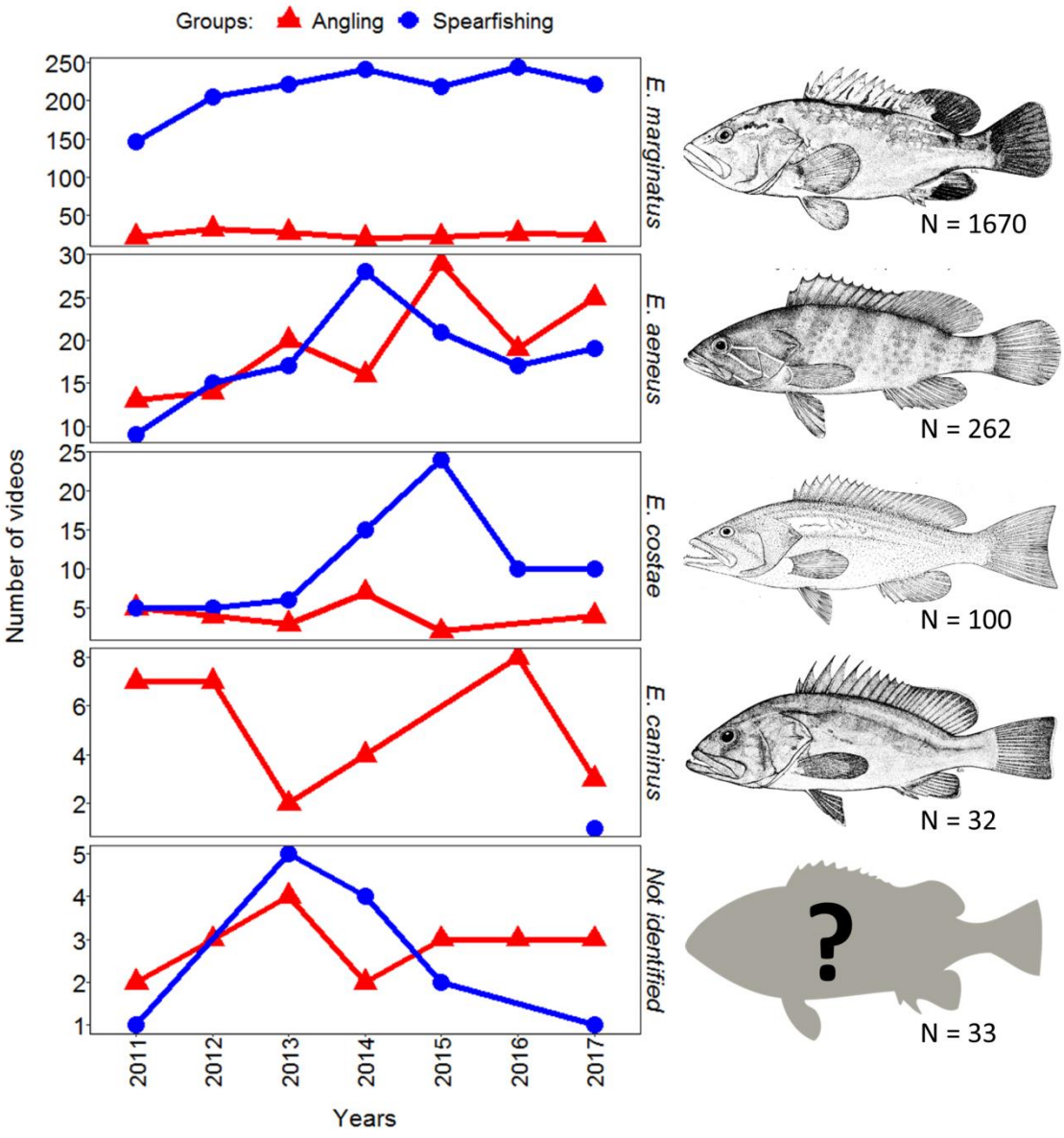

Figure 1 – The annual number of videos related to recreational fishing of groupers mined on YouTube between 2011 and 2017 in Italy. The annual number of videos is reported for each species according to the recreational fishing modality (angling: red triangles; spearfishing: blue circles) together with the videos where the species was not identified. The images of the groupers are adapted from Heemstra (1993).

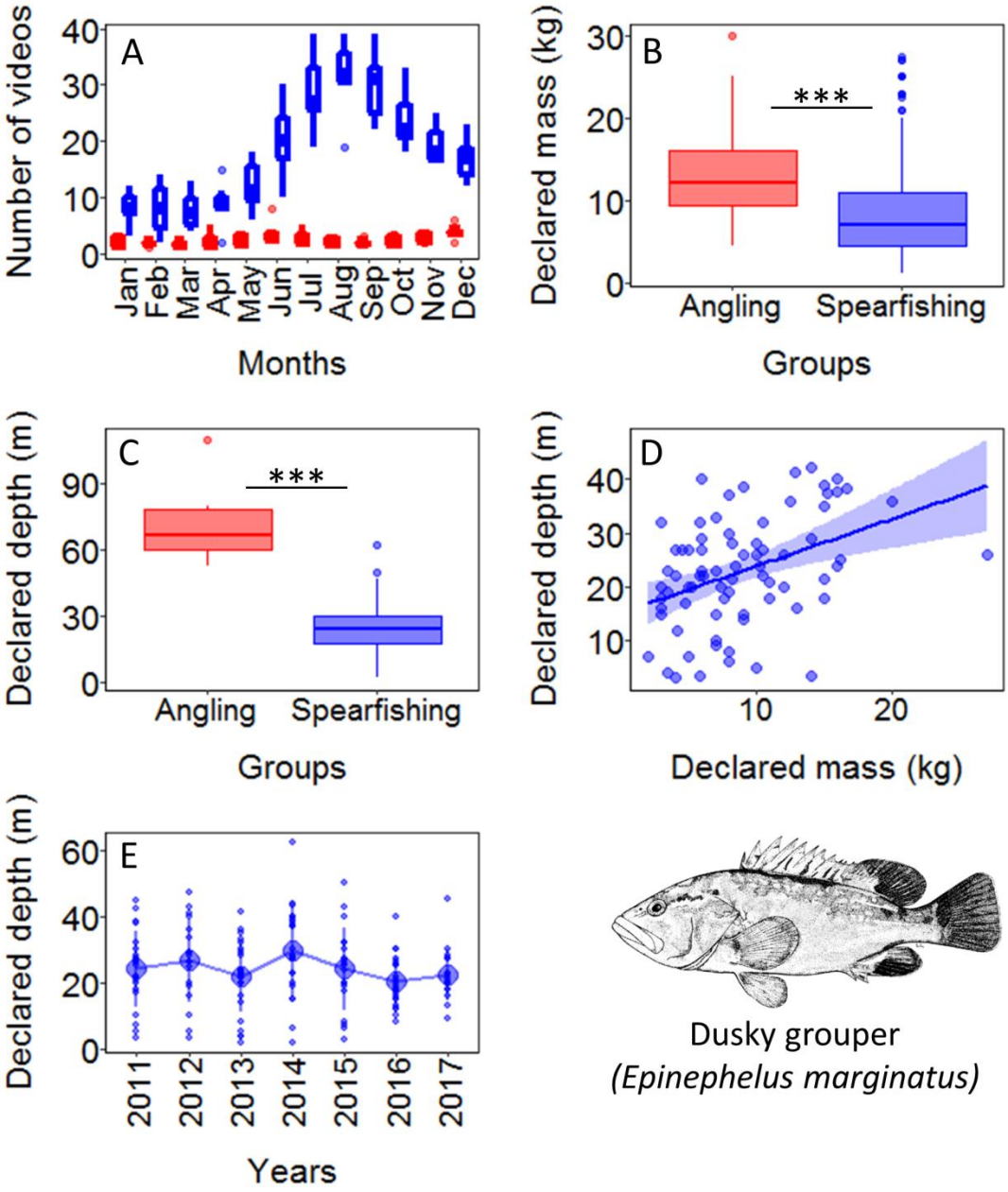

Figure 2 – The summary of the data for the videos related to recreational fisheries of the dusky grouper (Epinephelus marginatus) between 2011 and 2017 in Italy: (A) The number of uploaded videos for each month (angling: N=171; spearfishing: N=1499); (B) the declared mass (kg) for recreational anglers (N=34) and recreational spearfishers (N=426); (C) the declared depth (m) for recreational anglers (N=6) and recreational spearfishers (N=149); (D) the linear correlation and 95% confidence interval between declared mass (kg) and declared depth (m) for recreational spearfishing (N=75); (E) the declared depth (m) for each year (small circles) together with the mean (large circles) and standard deviation (vertical lines) for recreational spearfishing (N=149). The black horizontal line represents significant differences between groups (***: $p < 0.001$). The image of the grouper is adapted from Heemstra (1993).

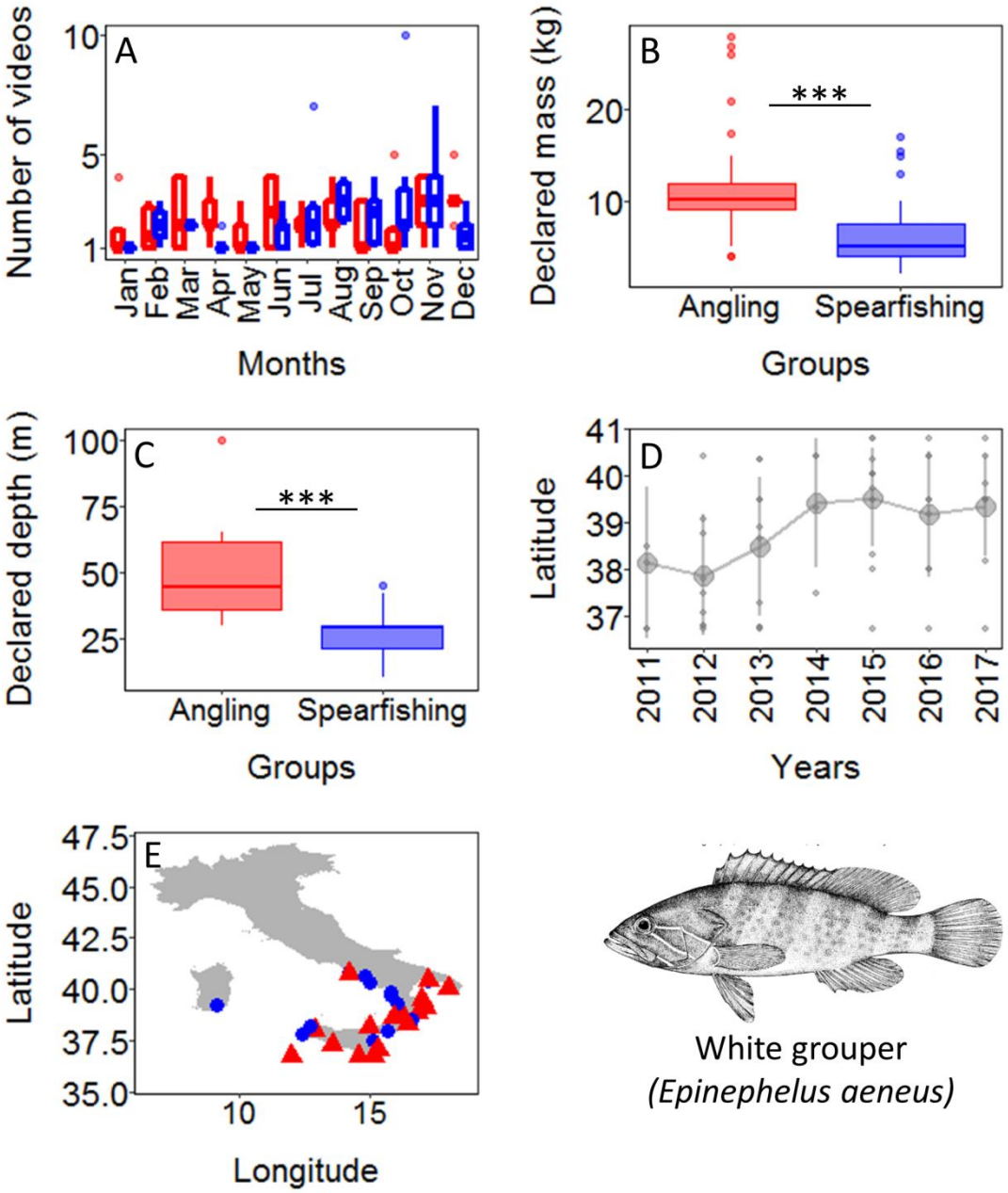

Figure 3 – The summary of the data for the videos related to recreational fisheries of the white grouper (Epinephelus aeneus) between 2011 and 2017 in Italy: (A) The number of uploaded videos for each month (angling: N=136; spearfishing: N=126); (B) the declared mass (kg) for recreational anglers (N=42) and recreational spearfishers (N=25); (C) the declared depth (m) for recreational anglers (N=6) and recreational spearfishers (N=15); (D) the latitude (small circles) of the location retrieved from the videos for each year together with the mean (large circles) and standard deviation (vertical lines) for recreational anglers and spearfishers (N=64); (E) the geographical distribution of the videos according to the information retrieved in their title, description as well as in the video itself. Red triangles represent recreational angling, while blue circles represent recreational spearfishing. The black horizontal line represents significant differences between groups (***: $p < 0.001$). The image of the grouper is adapted from Heemstra (1993).

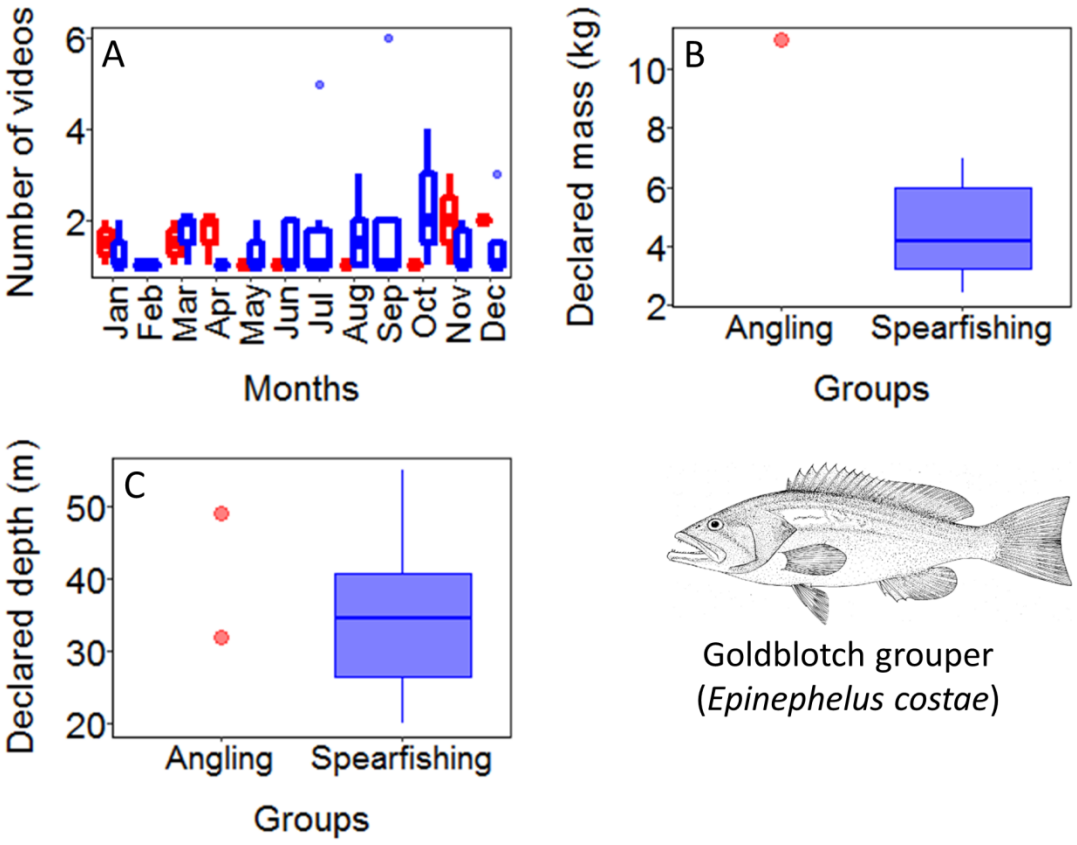

Figure 4 – The summary of the data for the videos related to recreational fisheries of the goldblotch grouper (Epinephelus costae) between 2011 and 2017 in Italy: (A) The number of uploaded videos for each month (angling: N=25; spearfishing: N=75); (B) the declared mass (kg) for recreational anglers (N=1) and recreational spearfishers (N=14); (C) the declared depth (m) for recreational anglers (N=2) and recreational spearfishers (N=10). The image of the grouper is adapted from Heemstra (1993).

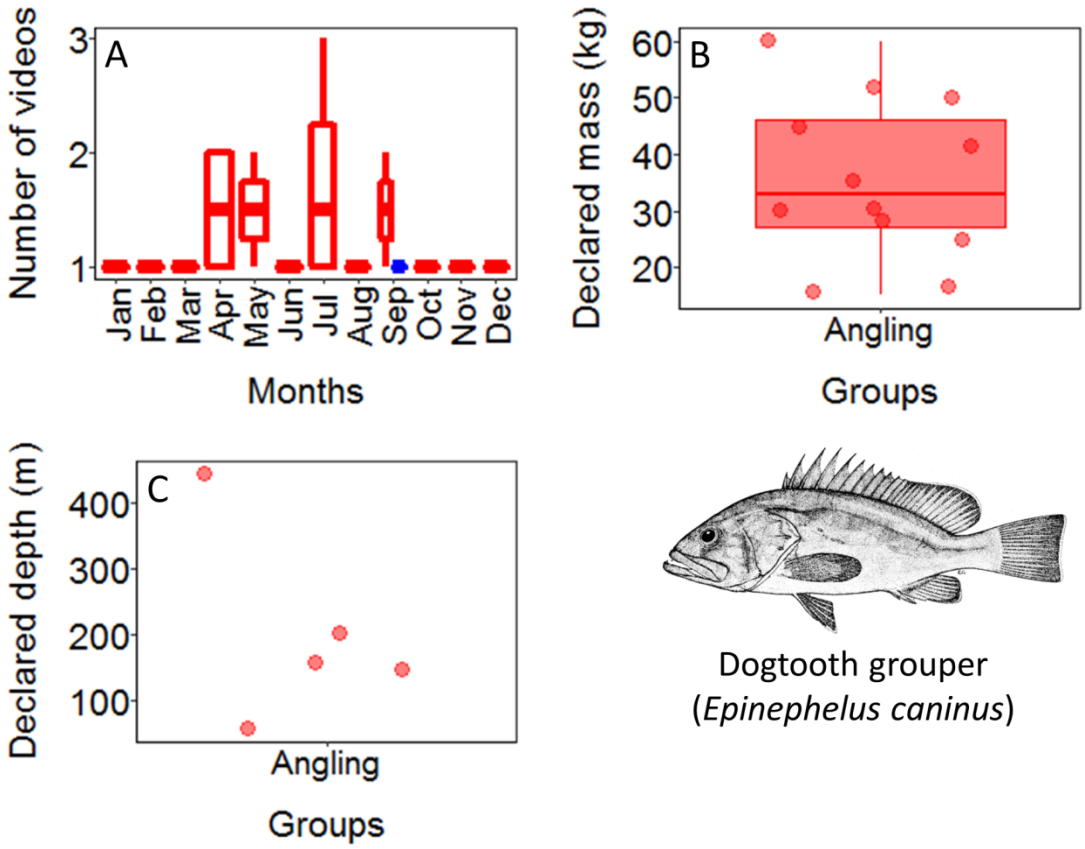

Figure 5 – The summary of the data for the videos related to recreational fisheries of the dogtooth grouper (Epinephelus caninus) between 2011 and 2017 in Italy: (A) The number of uploaded videos for each month (angling: N=31; spearfishing: N=1); (B) the declared mass (kg) for recreational anglers (N=12); (C) the declared depth (m) for recreational anglers (N=5). The image of the grouper is adapted from Heemstra (1993).

SUPPLEMENTARY INFORMATION

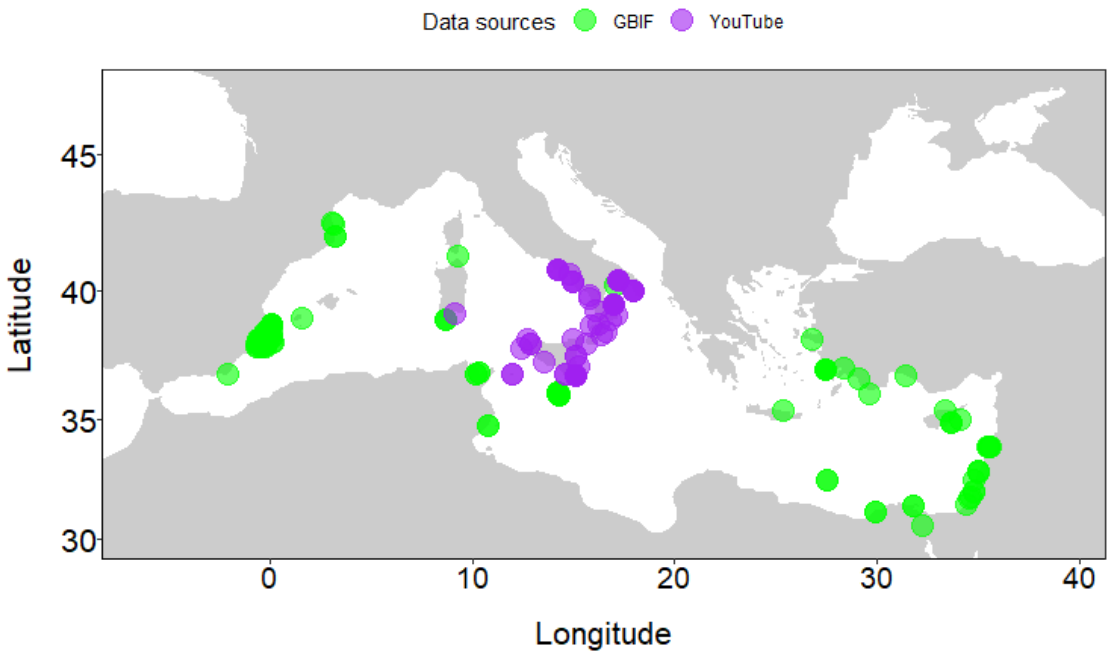

Figure S1 – Representation of the Mediterranean Sea showing all the occurrence records of the white grouper (Epinephelus aeneus) available in the Global Biodiversity Information Facility (green circles, N = 122; GBIF.org, (25 August 2020) GBIF Occurrence Download: https://doi.org/10.15468/dl.bdmkpb) together with the georeferenced catches documented here using data mining on YouTube between 2011 and 2017 (purple circles, N = 64; see also Fig. 3E for more details).